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PERFORMANCE OF SEVEN INTRODUCED HARDWOOD SPECIES ON EXTREMELY STONY MUCKS IN HAWAII

Craig D. Whitesell

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Whitesell, Craig D.
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Before a tree species is used in reforestation, its adaptability to planting sites should be demonstrated. Introduced hardwood timber species were planted at four sites on extremely stony muck soils on the island of Hawaii. Survival, growth, vigor, and tree quality of three species at age 10—Australian toon, tallow-wood eucalyptus, Queensland-maple—proved satisfactory at 2700- to 2800-feet elevation; performance of the other four species being tested was unsatisfactory at the elevations planted. These four are blackwood, Nepal alder, tropical ash, and blackbutt eucalyptus. Performance varied greatly, within and between all species tested. This variation was attributed to wide differences in soil depth and soil drainage.

Oxford: 232.11:(969)[+176.1 *Eucalyptus microcorys* + 176.1 *Flindersia brayleyana* + 176.1 *Toona ciliata*]
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Introduced hardwood trees can, when adapted to the local site conditions where they are planted, grow very fast in Hawaii.[1] Soil and climatic conditions in the State are extremely varied and often adverse. Therefore, experimental plantings should first demonstrate a species' adaptability at a location before it is planted for large-scale reforestation.

During the mid-1950's, reforestation was started on rain forest sites at elevations of 800 to 4500 feet (245 to 1370 m) on the slopes of Mauna Loa, island of Hawaii. Annual rainfall in this area ranges from 100 to 250 inches (2500 to 6350 mm). Soils are thin, extremely stony mucks overlying aa or pahoehoe lava rock, and are usually well drained.

To obtain more information about adaptability, growth, and yields on these stony mucks, the Hawaii Division of Forestry, in cooperation with the U.S. Forest Service, established four experimental plantings in 1962 and 1963. Seven introduced species were planted, none at more than two of the sites. Three of the four plantings consisted of mixed species; each involved three species planted alone and in admixture with another species. The tests were designed to determine if growth and stem quality could be improved by intermixing a tolerant species and an intolerant species. The fourth planting was a trial of blackbutt eucalyptus to determine growth response, quality, and yield at four spacing intervals.

The seven species planted were:

1. Blackwood (*Acacia melanoxylon* R. Br.)
2. Nepal alder (*Alnus nepalensis* D. Don.)
3. Tallow-wood eucalyptus (*Eucalyptus microcorys* F.v.M.)
4. Blackbutt eucalyptus (*Eucalyptus pilularis* Sm.)
5. Queensland-maple (*Flindersia brayleyana* F.v.M.)
6. Tropical ash (*Fraxinus uhdei* [Wenz.] Lingelsh.)

7. Australian toon (*Toona ciliata* var. *australis* F.v.M.)

Performance to date suggests that Queensland-maple, tallow-wood eucalyptus, and Australian toon are three species suitable for reforestation. They grew well on sites at 2700- and 2800-foot elevation. Queensland-maple and Australian toon have also grown well below this elevational range.[2] The three species should not be planted, however, on extremely shallow, poorly-drained lava rockland soils.

EXPERIMENTAL AREAS

The four experimental plantings lie on the east slope of Mauna Loa, southwest of Hilo, in the Waiakea and Olaa Forest Reserves, at four elevations: 2700, 2800, 2850, and 4200 feet (823 to 1280 m). Latitude is 19° 35′N and longitude is 155° 14′W.

Mean annual rainfall at 2800-foot (853 m) elevation was 206 inches (5227 mm), with extremes ranging from 167 to 270 inches (4242 to 6858 mm) annually during the period 1965-1974. The mean annual temperature was 64°F (18°C). The lowest temperature recorded was 41°F (5°C); the highest was 87°F (31°C).

At the 4200-foot (1280-m) site, the mean annual rainfall was 162 inches (4120 mm), but varied greatly over the 10-year period from 136 to 217 inches (3554 to 5512 mm). The mean annual temperature was 58°F (14°C). The lowest temperature recorded was 29°F (-2°C), the highest was 80°F (27°C) during the period 1965-1974.[1]

The rough terrain varies from nearly level to steep. The soils, classified as members of the Typic Tropohumults Subgroup,[3] have a surface layer of dark organic material about 8 inches (20 cm) thick overlying fragmental aa lava rock. Slightly weathered ash and cinders are in the voids of the lava. These soils have low inherent fertility and are highly acid (pH 4.5 to 5.5).[4] Soil depth and soil drainage vary greatly within short distances. Occasionally, pahoehoe lava bedrock occurs near the surface. Trees planted on these soils often succeed or fail just by chance, determined by the presence or absence of crevices in the underlying rock which the roots can penetrate.

Before the area was cleared for planting, it was a typical Hawaiian rain forest, where plants grow throughout the year. The major overstory tree species was ohia (*Metrosideros collina* [Forst.] Gray). The most numerous understory species were treeferns (*Cybotium* spp.).

METHODS

The mixed species planting trials were established at three elevations: 2700 feet (823 m), 2800 feet (853 m), and 4200 feet (1280 m). The plantings were laid out in a randomized block design, with four replications and six treatments. The treatments consisted of three species planted in pure plots and of combinations of two of the three species interplanted within rows. Plots were 60 feet (18.3 m) square, with isolation strips. Planting interval at the 2700-foot elevation site was 12 by 12 feet (3.7 by 3.7 m); the intervals at the 2800-foot and 4200-foot elevation sites were 10 by 10 feet (3 by 3 m).

Blackwood failed within 2 years and was replaced by Nepal alder in 1965. All dead or sickly tropical ash and Queensland-maple seedlings were replaced at that time (*table 1*).

All seedlings except the Nepal alder were grown in wooden flats, and then outplanted as balled-root 1-0 stock. The alder seedlings were 1-0 bare-root stock.

At age 3, the mixed species plantings were examined, and stem heights and diameters at breast height (d.b.h.) measured. Tree vigor was rated either "good" or "poor." The only cultural treatments practiced at this and subsequent measurements were weedings to release suppressed seedlings.

The blackbutt eucalyptus spacing trial, at a 2850-foot (869-m) elevation site, initially consisted of four replications of four spacing intervals laid out in a Latin-square design. Plot size varied, with 25 trees planted in each measure plot. High mortality and great differences in growth, related to the shallow soil and poor drainage, caused that study to be terminated after 3 years. All but four of the 16 plots were abandoned. These four plots, representing the four spacing intervals, were included in a followup study to evaluate the subsequent performance of blackbutt eucalyptus on this adverse site. The trees on these four plots were examined and measured at age 3.6 years.

The trees at all four sites were subsequently remeasured at various times between the ages of 8 to 12 years. Heights, d.b.h., and vigor were tallied. The stem quality of each tree was graded as "acceptable" or as "cull." An acceptable tree was one that had when measured, or had the potential to have, a butt sawlog length of at least 12 feet (3.7 m) without a serious defect. Cull factors were forking, excessive sweep or crook, lodging, lean exceeding 8 degrees, heavy branching below 12 feet, or being overtopped and of low vigor.

RESULTS

Of the seven species planted, only three had high survival and grew well—Australian toon, Queensland-maple, and tallow-wood eucalyptus.

Acacia melanoxylon—Blackwood acacia, planted at 4200 feet, had low survival and poor vigor, and was soon infested with cottonycushion scale (*Icerya purchasi* Maskell) and mites (*Oligonycus* sp.). After 2 years, all survivors were pulled out and discarded.

Alnus nepalensis—Nepal alder, which replaced the blackwood acacia at the 4200-foot site, proved unsatisfactory because of its poor form. Most of the trees had multiple stems, sweep, crook, and excessive branching. Only 3 percent had acceptable stem quality. More than one-third of the trees had died by age 8.5 years, and 22 percent of this mortality was caused by windthrow. Average annual height growth was 2.4 feet (0.7 m) (*table 1*).

Eucalyptus microcorys—Tallow-wood eucalyptus, planted on two sites at 2700- and 2800-foot elevations, performed well. Survival of 10-year-old trees

Table 1—*Survival, height and diameter growth, and condition of survivors of six introduced tree species planted on stony muck soils, by elevation and seedling age, island of Hawaii, 1975*

Site elevation (feet)	Age[1]	Number planted[2]	Survival	Height			Diameter		Condition of survivors		
				Average	Range	Periodic annual increment	Average	Range	Good vigor	Stem in live crown	Acceptable growing stock[3]
	Years		*Percent*	*Feet*			*Inches*		*Percent*		
Nepal alder (*Alnus nepalensis*)											
4200	0.7	286	83	1	1- 2	–	–	–	88	–	–
(1280 m)	8.5		63	[4]20	[4]11-38	[5]2.4	[4]4.1	[4]1.4- 8.0	[4]71	–	3
Tallow-wood eucalyptus (*Eucalyptus microcorys*)											
2700	3.1	96	88	11	2-19	3.5	1.2	0.1- 2.6	98	–	–
(823 m)	10.4		68	42	14-65	4.2	6.4	1.3-11.3	90	65	86
2800	3.2	288	91	8	2-20	2.5	0.8	0.1- 2.7	96	–	–
(853 m)	10.4		87	30	11-55	3.1	4.0	1.0-12.0	73	57	78
Blackbutt eucalyptus (*Eucalyptus pilularis*)											
2700	3.1	192	84	7	2-25	2.3	0.9	0.1- 3.4	71	–	–
	10.4		46	34	12-76	3.7	4.4	1.0-13.1	58	48	75
2850	3.6	100	91	8	1-24	2.2	1.2	0.4- 4.2	68	–	–
(868 m)	12.5		44	35	12-85	3.0	5.0	1.0-12.0	50	43	45
Queensland maple (*Flindersia brayleyana*)											
2700	3.1	96	94	9	1-16	2.9	1.1	0.4- 2.3	98	–	–
	10.4		89	36	11-51	3.7	5.2	1.1- 9.4	88	64	92
4200	3.2	292	92	2	1- 8	0.6	0.6	0.3- 0.9	77	–	–
	11.0		36	18	9-29	2.1	2.2	1.0- 6.0	39	37	30
Tropical ash (*Fraxinus uhdei*)											
2800	3.2	288	98	12	1-25	3.8	1.4	0.3- 2.7	98	–	–
	10.4		96	27	10-43	2.1	4.5	1.0- 9.5	86	70	49
4200	3.2	286	100	10	1-21	3.1	1.1	0.3- 2.2	97	–	–
	11.0		83	21	8-34	1.4	2.5	1.0- 7.5	57	56	31
Australian toon (*Toona ciliata* var. *australis*)											
2800	3.2	287	89	10	1-25	3.1	1.3	0.2- 3.7	92	–	–
	10.4		86	27	11-55	2.4	4.0	1.0- 9.3	73	63	89

[1] Calculated from date of planting.
[2] Excludes 1 or more buffer rows around each plot.
[3] Trees that have, now or potentially, a butt sawlog length of at least 12 feet (3.7 m) and are not culled because of forking, lean, excessive sweep or crook, or some other cull factor.
[4] Basis: 17 measurable trees.
[5] Mean annual increment; basis 17 trees.

averaged 82 percent; heights ranged from 11 to 65 feet (3.4 to 19.8 m), and averaged 33 feet (10 m). Diameters averaged 4.5 inches (11.4 cm). Seventy-seven percent of the trees were rated as vigorous; 79 percent were of acceptable quality. The major culling factors for tallow-wood were forking below 12 feet (3.7 m), excessive lean, and very low vigor. Windthrow, occurring on shallow soils, accounted for one-third of the mortality at the lower site. No windthrow occurred at the 2800-foot elevation site.

Eucalyptus pilularis—Blackbutt eucalyptus was unsatisfactory on these extremely stony muck soils. At the 2700-foot elevation site, survival was 46 percent. Trees averaged 34 feet (10 m) tall at age 10 years. One individual was 74 feet (23 m) tall, with a d.b.h. of 13 inches (33 cm). After 10 years, only 58 percent of the trees were judged as vigorous, but 75 percent of the trees had acceptable tree quality. Windthrow was the cause of 14 percent of the mortality.

Planted at 2850-foot elevation in pure blocks, blackbutt eucalyptus was even less promising, regardless of spacing, with lower survival, slower growth, and fewer vigorous trees. Only 45 percent of the surviving trees were of acceptable quality. Seedlings suffered crown dieback or death from an unidentified root disease associated with poor soil drainage.

Flindersia brayleyana—Queensland-maple was a success at the 2700-foot elevation site. Survival was good (89 percent) and mean annual height growth was 3.5 feet (1.1 m) for the 10-year period. Mean annual diameter growth was 0.5 inch (1.3 cm). Eighty-eight percent of the trees were considered vigorous; and only 8 percent were classified as cull trees.

The performance of Queensland-maple at the 4200-foot elevation site was unsatisfactory. Survival decreased from 92 percent at age 3 to 36 percent at age 11, and only 30 percent of the survivors were of acceptable quality. Average annual height growth was only 1.6 feet (0.5 m), and vigor was poor.

Fraxinus uhdei—Tropical ash grew rapidly during the first 3 years, averaging more than 3 feet (1 m) annually, at both the 2800-foot and 4200-foot sites. Then height growth tapered off, averaging 2 feet (0.6 m) on the two sites during the next 7 years. Survival remained high at both sites, but the percentage of vigorous trees at the 4200-foot elevation site was much lower. There, 69 percent of the tropical ash were classified as culls, compared to 51 percent at the 2800-foot elevation site. Multiple stems, sweep, crook, and lodging accounted for the poor quality rating.

Toona ciliata, var. *australis*—Australian toon, planted only at the 2800-foot site, had high survival (86 percent) at age 10 years. Average annual height growth was 3.1 feet (0.9 m) during the first 3 years, and 2.4 feet (0.7 m) during the last 7 years. The percentage of vigorous trees decreased from 92 at age 3 to 73 at age 10. Tree quality was high, with 89 percent classified as acceptable.

DISCUSSION

The three species recommended for future timber crop plantings on these and similar sites are Queensland-maple, a valuable timber species comparable in quality to mahogany and walnut; tallow-wood eucalyptus, a fast-growing species useful for lumber, and Australian toon, a member of the mahogany family, with wood prized for furniture. All three species were growing vigorously on the planting sites and had acceptable stem form. Survival exceeded 82 percent 10 years after planting, and the larger individuals were growing into the sawtimber size category. Despite its satisfactory performance, Australian toon did not equal its growth in nearby plantations.[5] This species apparently is more site demanding than either Queensland-maple or tallow-wood eucalyptus, and its planting sites must be carefully selected.

Blackbutt eucalyptus is not recommended for planting on extremely stony mucks, despite its rapid growth on scattered, well-drained, deeper soil pockets. This species proved unsatisfactory for reforestation because of poor survival and vigor, and terminal dieback. Planted at the 1700-foot elevation site, in mixtures with Queensland-maple and with tallow-wood eucalyptus, it failed where the other two species succeeded.

A high percentage of cull trees, and unsatisfactory growth after age 3 years, caused tropical ash to be rated as unsatisfactory for timber production on the test sites.

At the 4200-foot elevation site, tropical ash, Queensland-maple, blackwood acacia, and Nepal alder were unsatisfactory because of low survival, poor form, or poor growth. Queensland-maple and tropical ash grew much slower at this site than at the 2700- and 2800-foot sites. At the higher elevation, temperatures are lower, and there is less solar radiation.

A second objective of the three mixed species trials was to evaluate species interactions to determine if growth and quality could be increased by planting in admixtures. At the 2700- and 4200-foot elevation sites, extreme variations in survival, growth, and stem form, both within and between plots,

prevented valid statistical comparisons among treatments. These variations relate to variable microsite conditions.

Comparisons among treatments were possible for tropical ash, Australian toon, and tallow-wood eucalyptus at the 2800-foot site. Differences among species at age 10 in height, height to live crown, diameter, or stem quality when planted alone or with another species, were not statistically significant (10 percent level of probability). However, crown closure had barely begun in most of the plots, and so interactions had not yet occurred. Perhaps no real differences in growth and quality among the various treatments will be apparent for another 5 to 10 years.

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NOTES

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The Author

CRAIG D. WHITESELL is assigned to the Station's Institute of Pacific Islands Forestry, headquartered in Honolulu, Hawaii. He is doing research on the silviculture of native and planted forests in Hawaii and on Guam. He received his bachelor's (1951) from West Virginia University, and his master's degree (1954) from Duke University–both in forestry. He has been with the Station's Hawaii staff since 1962.

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